IUTAM Symposium on Growing solids
June 23-27, 2015, Moscow, Russia

Impact Loading of Laminated Nanocomposites in Thermal Environment

G. Balaganesan [1], R. Velmurugan [1], and N. Gupta [2]

[1] Indian Institute of Technology, 600036, Chennai, India
gbganesh@iitm.ac.in

[2] Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India,
nkgupta@am.iitd.ac.in

Fibre reinforced polymer composites are widely used in aerospace and defense applications due to their light weight and tailorable properties to meet specific requirements. The structural components are subjected to high velocity impact by projectiles. In addition, these materials are subjected to loads at various thermal environment depending upon their applications. It is essential to study the behavior of these materials to understand the performance characteristics during impact as the impact forces induce matrix crack, fiber breakage, and delamination which will in turn affect the dynamic behavior of the material at thermal environment.

Choi and co-workers [1] conducted high-speed impact tests of satin-woven SiC/SiC composites at room temperature and 1316 °C using a burner rig, and reported significant post-impact strength degradation but with little difference in damage size. The authors [2] investigated the behavior of three-dimensionally woven SiC/SiC composites at room temperature and 800 °C, and observed embroiled damage characteristics in thermally exposed specimens. This embrittlement was ascribed to formation of the nanometer-scale oxidation layer at the fiber/matrix interface. However, studies on the behavior of thermally loaded polymer composites are limited, and the influence of thermal loading on the impact behavior has not been clarified.

This study investigates impact characteristics of thermally loaded nano composites. First, nano composite specimens are subjected to impact loading at 0° C, 30° C and 60° C temperatures. The damage patterns will be observed. Also, the ballistic limit will be predicted for the specimens of nano composites made with glass/epoxy fibers and matrix, and the effect of temperature on impact resistance will be discussed. Analytical model is developed and the energy absorption characteristics is also studied.

Energy absorption in laminates at room temperature

In the beginning of the impact, the entire energy is in the form of kinetic energy of the projectile. This energy is later shared by different failure mechanisms, projectile kinetic energy and kinetic energy of the moving cone. Considering the energy balance at the end of i^{th} time interval,

$$KE_o = E_{Pi} + E_{frac(i-1)} + E_{def(i-1)} + E_{delam(i-1)} + E_{matcrack(i-1)} \quad (1)$$

Where, KE_O is the initial kinetic energy of projectile, E_{Pi} are projectile energy at i^{th} instant of time, . E_{frac} is energy absorbed due to tensile failure of fiber, E_{def} is energy absorbed due to deformation of secondary fiber, E_{delam} is energy absorbed due to delamination, and $E_{matcrack}$ is matrix crack energy. Rearranging the terms,

$$\frac{1}{2}mV_o^2 - E_{(i-1)} = \frac{1}{2}mV_i^2 \, , \quad (2)$$

where m and V_o are the mass and initial velocity of the projectile at the i^{th} time interval.

$$E_{(i-1)} = E_{frac(i-1)} + E_{def(i-1)} + E_{delam(i-1)} + E_{matcrack(i-1)} \quad (3)$$

The energies shared in each time interval are explained in the following sections. The above energy is for $(i\text{-}1)^{st}$ time interval. From eqn. 2 the velocity of projectile at the end of i^{th} time interval is obtained by the following equation,

$$V_i = \sqrt{\frac{\frac{1}{2}mV_o^2 - E_{(i-1)}}{\frac{1}{2}(m)}} \quad (4)$$

Experimental results

The energy absorption of 2mm thickness glass/epoxy laminates with and without clay subjected to different velocities at 30° C is shown in Fig. 1. The laminates are tested for velocities at ballistic limit and above ballistic limit at 135 m/s, 140 m/s, and 145 m/s. In all the cases the laminates without clay absorb less energy than the laminates with 1-5% clay. The increase in energy absorption is high for the laminate with 5% clay when compared to laminate without clay. At the velocity of 135 m/s the increase in percentage of energy absorption for laminate with 2%, 3%, 4% and 5% clay is 37%, 41%, 45% and 50% respectively when compared to the laminate without clay. Clay dispersion up to 2% shows good improvement in energy absorption. When the laminate is subjected to velocity of 145 m/s, the decrease in percentage of energy absorption is observed for the laminate without clay and for the laminates with clay up to 4%. Rate of improvement is high for laminates with 2% clay.

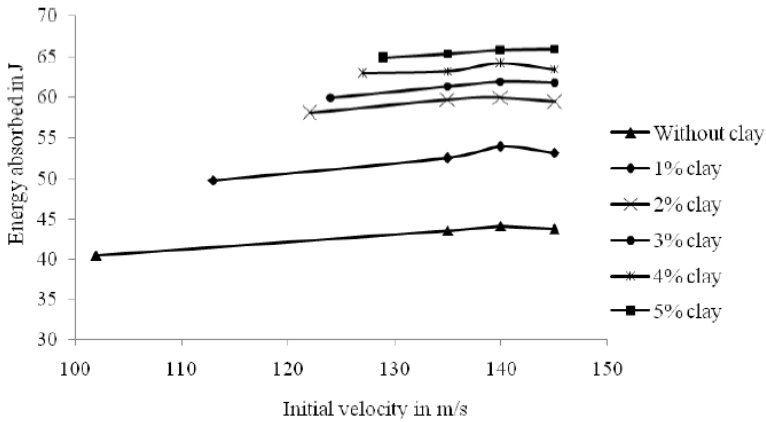

Figure 1: Initial velocity vs energy absorbed for three layer laminates

The experimental results for energy absorption of the laminates are calculated on the basis of the initial and residual energies of the projectile. The model predicts the change in projectile energy with reference to time during perforation of the laminates and energy absorbed by the laminates in various failure modes like deformation of secondary fibers, delamination, matrix crack and tensile failure of primary fibers. The ballistic limit obtained from the model is validated with experimental results, and good agreement is found.

Reference

[1] *S. R. Choi, D. J. Alexander, and R. W. Kowalik*. Foreign object damage in an oxide/oxide composite at ambient temperature. J Eng Gas Turb Power 2009; 131(2):021301.

[2] *K. Ogi, T. Okabe, M. Takahashi, S. Yashiro, A. Yoshimura, and T. Ogasawara*. Experimental characterization of high-speed impact damage behavior in a three-dimensional woven SiC/SiC composite. Composites Part A 2010; 41(4):489–98.